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LEP TUNNEL
MOVEMENTS AT POINT 1 CAUSED BY LHC CIVIL ENGINEERING

H. Rammer

Abstract

The excavation of underground openings causes the surrounding ground to move towards the newly created opening. The magnitude of the movement is dependant of various factors, such as the shape and the size of the excavation, the geotechnical ground conditions, the in-situ ground stress, the distance from the excavation, etc. The excavation technique and the rock support measures are to be adapted to the prevailing ground conditions to limit the displacements to an acceptable level. From the output of the numerical analyses for the design of the underground structures, data can be obtained to determine the predicted movements. For the particular case of the LHC excavations at Point 1 in close proximity to the existing LEP tunnel, a facility had to be designed and installed in the LEP tunnel to allow adjustments of the machine alignment to compensate for the tunnel movements. The design was based on the predicted displacements, and the adequacy of the facility has been validated during excavation.

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1 INTRODUCTION

The LHC civil engineering construction at Point 1 started in 1998, two and a half years before the final LEP shutdown scheduled for October 2000. To meet the tight overall LHC project programme, the excavation for some underground structures had to commence while the LEP accelerator was still in operation. These excavations caused the existing LEP tunnel in close proximity to move. The predicted movements were of sufficient amplitude to prevent machine operation if no precautions were taken.

2 LHC CIVIL ENGINEERING AT POINT 1

The new underground works for the LHC at Point 1 comprise new caverns, shafts and galleries to be built in and around the existing underground structures of LEP. The principal works are the new UX15 ATLAS experimental cavern, a huge underground opening of unprecedented size which will be built parallel to the existing beam tunnel; the USA15 service cavern, perpendicular to UX15 and smaller in span but bigger in length than UX15; and two new access shafts as well as various smaller tunnels and chambers.

The final inner dimensions of the UX15 cavern are 53 m in length, 30 m in width and 35 m in height. The USA15 is a 62 m long cavern with a springline diameter of 20 m. The two access shafts measure 60 m in depth down to crown level of UX15, the bigger of which, PX14, with 18 m internal diameter, and the smaller PX16 shaft with 12.6 m diameter.

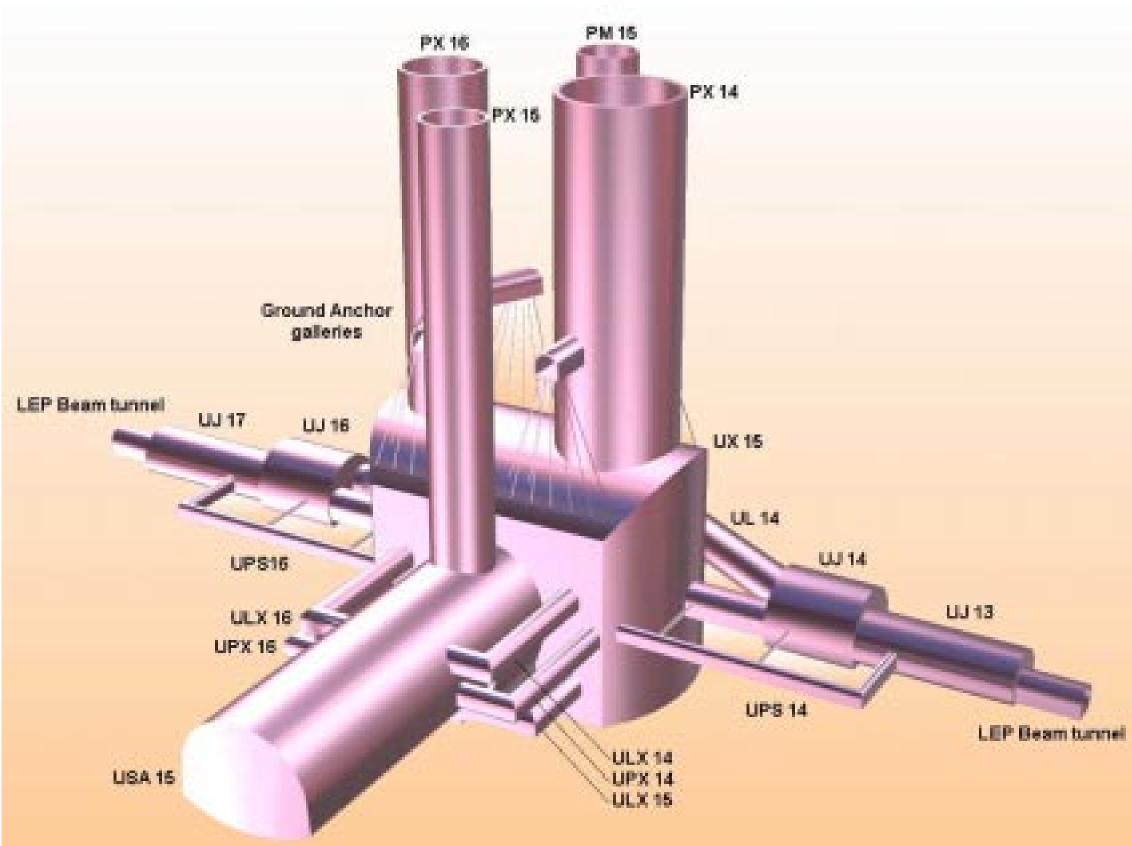

Figure 1: General arrangement of underground works at point 1.

3 PROGRAMME CONSTRAINTS

The overall LHC project schedule require the civil engineering to complete the underground works at Point 1 three years before the planned commissioning date of the LHC in the year 2005. To meet this tight schedule and to complete the new underground works in time, civil engineering work at Point 1 started early 1998, two and a half years before the final shutdown of the LEP accelerator in October 2000. Much of the new underground works were to be constructed before that date, while the existing LEP machine was still operational. The construction sequence and construction methods for the underground works had to be adapted in order not to disturb the functioning of the machine.

The retained construction sequence allowed for the excavation of the whole of the USA15 service cavern and the vault section of the UX15 cavern prior to LEP shutdown, leaving the bulk excavation of the UX15 bench and invert until after the dismantling of the LEP. The use of explosives for rock excavation was forbidden, and the contractor has chosen to use mechanized excavators with hydraulic chisel hammers to break the rock.

4 DESIGN OF THE UNDERGROUND WORKS

4.1 Rock Mass Behaviour

The excavation of underground openings causes the surrounding ground to move towards the newly created opening. The initial stresses prevailing in the ground are to be redistributed around the new opening. This redistribution of the initial stresses may lead to localized stress concentrations which, depending on the strength of the surrounding rock, may cause the rock mass to fail. Primary rock support measures, e.g. rock bolts and shotcrete, may be installed to strengthen the rock mass, to prevent it from failing and to limit the deformations to an acceptable range.

In the design of the underground excavations, numerical models may be employed to analyse the rock mass behaviour and to develop suitable rock support measures. The results of such numerical analyses may be used to estimate the likely movements of the ground.

4.2 Predicted Movements

In the case of the LHC civil engineering at Point 1, the design had to take into account the programme constraints described above and the vicinity of the existing LEP tunnel to come up with an appropriate construction sequence. A compromise had to be found between the need to carry out as much work as possible before the LEP shutdown without excavating too close to the LEP tunnel and not to cause unacceptable large displacements of the tunnel and thus the LEP machine. The design assumed the excavation of the whole of the USA15 cavern as well as the two new shafts PX14 and PX16 and the vault section of the UX15 cavern before the LEP shutdown.

Given the complexity of the new works in the vicinity of the existing structures and the particular geological conditions on site, various numerical models have been developed to meet the objectives identified above. A series of two-dimensional and three-dimensional models were used to address the different design requirements. Two-dimensional models were used to analyse in detail the geotechnical behaviour of the rock, the foreseen rock support measures and the short term and long term effects on the structural linings. However significant engineering assumptions had to be incorporated into the 2D-models to take into account the geometry of the works and the interaction between the different excavations. Due to the geometrical complexity of the underground structures, three-dimensional models were imperative to analyse the global behaviour of the works. A first 3D-model has been developed for the principal excavations, however certain restrictions had to be made on the geological representation of the rock mass and on the consideration of the rock support measures. Subsequently a number of smaller local 3D-models have been used to analyse in more detail some specific areas of particular interest, for example the intersections between the shafts and the caverns or to take into account in detail the retained phasing of the excavation. Finally the results from the simplified three-dimensional models have been cross checked and validated with the analyses of the two-dimensional models.

The numerical models were then used to determine the effects of the excavation for the new works on the existing structures, in particular in terms of likely movements of the beam tunnel. It resulted in a predicted maximum vertical heave of the LEP tunnel of 30 mm due to the excavation of the UX15 vault some 10 m above the tunnel crown. In addition, 5 mm of horizontal movements of the LEP tunnel were calculated resulting from the excavation of USA15.

5 EFFECTS OF THE TUNNEL MOVEMENTS

5.1 Beam Alignment

During the civil engineering design phase, the predicted tunnel movements have been discussed with the machine operation and survey groups, and the possible effects on the machine alignment have been investigated. It was found that the standard beam optics were capable of compensating about 20% of the predicted displacements. For further displacements beyond this limit, a system of physical re-alignment had to be developed and implemented. In addition, a high precision monitoring system was considered to be indispensable for the displacement measurement of the machine components and the control of physical re-alignment campaigns.

Because the predicted movements of the LEP tunnel were upwards, it was necessary to lower the machine components as the tunnel floor raised. The magnets were modified to accommodate up to 40 mm of vertical movement. This was achieved by installing new jacks in newly sunken holes below the girders. Modifications were also made to allow the required horizontal movement.

5.2 Survey System

The new LEP position monitoring system consisted of a stretched wire along the beam tunnel across the zone likely to be affected by the ground movements, and detectors measuring their position relative to the wire. The wire, made from carbon and surrounded by a kevlar channel to protect it from air currents in the tunnel was attached to two supports at either end, about 130 m apart, thus being considered unaffected by the tunnel movements and stable. Eleven detectors were positioned along that portion of the tunnel likely to be affected and mounted on the tunnel floor, thus any movements of the tunnel floor moved the detectors the same way. With the wire providing a fixed reference, the detectors measured their horizontal and vertical movements relative to the wire.

The displacement monitoring system had been installed in the LEP tunnel during the 1998/1999 annual winter shutdown, and was operational during the subsequent excavation phases of the new shafts and caverns. The position of the wire was measured to an accuracy of ±0.1 mm. The signals from the detectors were treated in electronics located away from the radiation area and were connected to the CERN control system where the data was logged.

6 CONCLUSION

The predicted tunnel movements necessitated precautions to be taken to prevent failures of machine operation and to ensure smooth running of the LEP machine during its final operational period. The standard optics were capable of compensating up to 20% of the predicted movements. Physical re-alignment of the machine components was planned to be performed manually as required. The position monitoring system installed in LEP allowed continuous monitoring, and interventions for re-alignment could be scheduled at a convenient time. The actual tunnel movements caused by the excavations for the USA15 cavern and the UX15 cavern vault reached an amplitude of up to 35% of the predicted movements. One physical re-alignment campaign was necessary to be carried out in September 2000. The implemented modifications to the machine components proved to be adequate and effective, and this has been confirmed by a successful run of the LEP machine in its final year at peak performance.

REFERENCES

[1] B. Goddard et al., “Final Report on the Consequences of LHC Civil Engineering for the SPS and LEP”, CERN-SL/97-66 and CERN-ST/97-01, Dec. 1997.